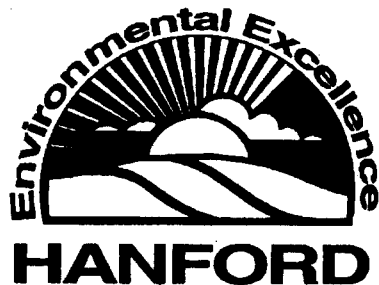


BHI-01141
Rev. 0

100 Area River Effluent Pipelines Risk Assessment



Prepared for the U.S. Department of Energy
Office of Environmental Restoration

Bechtel Hanford, Inc.
Richland, Washington

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BHI-01141

Rev. 0:

OU: N/A

TSD: N/A

ERA: N/A

APPROVAL PAGE

Title of Document: 100 Area River Effluent Pipelines Risk Assessment

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Author
P. G. Doctor

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ACRONYMS

ERA	Expedited Response Action
GPR	ground penetrating radar
MATC	maximum acceptable toxicant concentration
TCLP	toxicity characteristic leach procedure
WHC	Westinghouse Hanford Company

1.0 INTRODUCTION

This document evaluates the current and future risks to humans and the environment associated with the 100 Area reactor effluent pipelines at the Hanford Site. The effluent pipelines are the subject of an Expedited Response Action (ERA). The U.S. Environmental Protection Agency is a co-lead agency, and the Washington State Department of Ecology is the other co-lead agency. This ERA is classified as non-time critical.

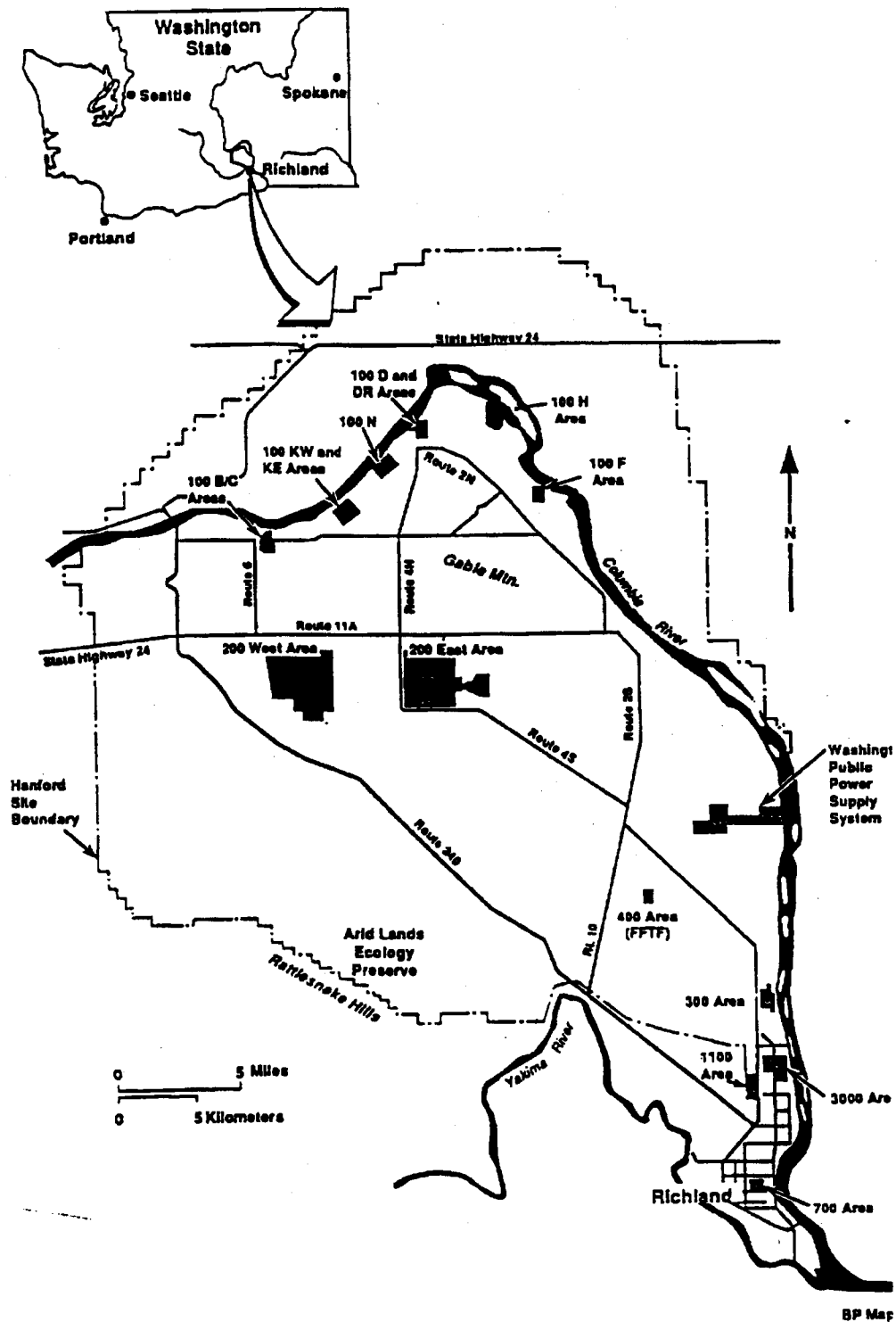
2.0 BACKGROUND

From 1943 to the present, the Columbia River has been used as a water supply by the Hanford Nuclear Reservation. All of the reactors (Figure 1), except 100-N, used the river water for primary reactor core cooling purposes. The 100-N system provided river water to a secondary water-cooling loop. The river discharge lines are part of each reactor's effluent system. Most lines stopped operating when the associated reactor was shut down or soon thereafter (Table 1). One of the two K lines still services the K Area.

Table 1. River Discharge Line Operating Histories.

Reactor Area	Initial Reactor Startup Date	Final Reactor Shutdown Date	Years Operated
100-B	9/44	2/68	23
100-C	11/52	4/69	16
100-D	12/44	6/67	23
100-DR	10/50	12/64	14
100-F	2/45	6/65	20
100-H	10/49	4/65	15
100-KE	4/55	1/71	16
100-KW	1/55	2/70	15
100-N	12/63	2/88	25

Figure 1. 100 Area Reactor Location Map.



The land portions of the effluent pipe systems are below ground at all reactors except 100-F, where a portion of the system was above ground. Each line extends from its associated reactor into retention basins then into an outfall structure and then into the main Columbia River channel outlet. Outfalls are open, reinforced concrete structures that direct water through either the river discharge lines or through spillways. The spillways are the concrete flumes that discharged to the shoreline; they were used when the river lines were blocked, damaged, or undergoing maintenance, or when the flow rate exceeded the capacity of the lines.

The concrete river discharge lines ran from the outfall structure down to the river-bottom-level junction. Same-diameter steel pipes continued from the junction on a level run to the river outlet. Typically, a shallow river bed trench was excavated. The pipe was joined using butt welds, dresser couplings, and ground jumpers. Concrete cones anchored the lines, and three feet of fill buried the piping. A final anchor and boulder rip-rap secured the pipe outlet. A smooth round lip modified the pipe mouth.

During reactor operation, released cooling water went to a retention basin located between the reactor building and the river. Water retention permitted thermal cooling and the decay of short-lived radioisotopes prior to river discharge. As reactor production increased, the hold-up period decreased. The retention basins also served to hold up the flow of effluent with high radioactive isotope concentrations that resulted from fuel element failure. This higher-concentration effluent was isolated and diverted either by gravity or pumping to trenches, which filtered the effluent through the soil before it reached the groundwater adjacent to the river edge.

2.1 PHYSICAL DESCRIPTION OF THE EFFLUENT PIPELINES

The following descriptions are based on a 1986 inspection (Beckstrom and Steffes 1986) and a 1994 survey (WHC 1994). All effluent lines discharge underwater, generally in the center of the river channel. Tables 1 and 2 summarize the pipeline history and physical data. There are 14 pipelines that are part of this ERA:

- 100-B river lines (2)
- 100-C river lines (2)
- 100-D and 100-DR river lines (3)
- 100-F river lines (2)
- 100-H river lines (2)
- 100-K river lines (2)
- 100-N river line (1).

The pipelines are described in more detail in the following subsections.

2.1.1 B Pipelines

The B effluent piping consists of two outfalls (116-B-7 and 116-B-8). These outfalls feed two river discharge lines (Figure 2). From the 116-B-7 Outfall, the effluent discharged through a 42-in.-diameter welded carbon steel pipeline with a ½-in.-thick wall. The discharge line from the 116-B-8 outfall is a 66-in.-diameter carbon steel line with a ½-in.-thick wall.

Large cobbles and boulders cover the 116-B-7 pipe river bed area. The pipeline extends about 400 ft offshore, and the last 40 ft are exposed on the river floor. The pipeline relief, where it is exposed, varies from 2 to 3 ft. The burial sediment depth varies from 1 to 3 ft (WHC 1994).

Large cobbles and boulders cover the 116-B-8 riverbed area. This pipeline extends about 400 ft offshore, and the last 100 ft are exposed on the riverbed. The pipeline relief, where it is exposed, varies from 1 to 3 ft. The burial sediment depth varies from 1 to 3 ft (WHC 1994).

Table 2. River Discharge Line Physical Data.

Area	Pipe Diameter cm (in.)	No. of Lines	Total Length m(ft)	Outfall Structure Status
100-B	107(42)	1	228(750)	*116-B-7 Standing
100-B	168(66)	1	210(690)	*116-B-8 Demolished
100-C	137(54)	2	152(500)	*116-C-4 Demolished
100-D	107(42)	2	564(1850)	*116-D-5 Standing
100-DR	152(60)	1	549(1800)	*116-DR-5 Demolished
100-F	107(42)	2	91(300)	*116-F-5 Demolished
100-H	152(60)	2	252(825)	*116-H-5 Demolished
100-K	210(84)	2	396(1300)	**1904-K Standing
100-N	259(102)	1	320(1050)	**1904-N Standing

* Facility remediation designating nomenclature

** Original Facility designating nomenclature

2.1.2 C Pipelines

The C effluent system discharged from the 132-C-2 Outfall through two 54-in.-diameter steel lines with ½-in.-thick walls (Figures 2 and 3).

Large boulders that project up to 3 ft above the riverbed are present throughout this site. The parallel pipelines extend about 300 ft offshore. Both pipes are exposed at various locations along the pipe run. The sediment burial depth for both pipes varies from 1 to 3 ft (WHC 1994).

2.1.3 D and DR Pipelines

The D and DR effluent piping has two outfall structures (116-D-5 and 116-DR-5) feeding three river discharge lines (Figures 4, 5, 6, and 7). From the 116-D-5 Outfall, the effluent discharged through two 42-in.-diameter reinforced concrete/steel pipes. The steel pipe has ½-in.-thick walls. From the 116-DR-5 Outfall, the discharge line is a 66-in.-diameter carbon steel line with a ½-in.-thick wall. The three pipelines pass through the 100-D island; when operating, they discharged into the main river channel.

The river bed along these two parallel pipe runs appears to be relatively smooth and is covered with sand, gravel, and cobbles. The pipe runs are about 500 ft apart. Both pipe runs extend about 1300 ft into the river. The D pipelines are buried along their entire run to a depth of about 2 to 7 ft; the outlets are not exposed on the river bed. The DR pipeline is buried along the entire run from 2 to 6 ft; the outlet is exposed on the riverbed (WHC 1994).

2.1.4 F Pipelines

The F Reactor effluent system has the 116-F-8 Outfall feeding two lines (Figures 8 and 9). The discharge was through two 42-in.-diameter reinforced concrete/steel pipe lines. The pipes have ½-in.-thick walls. Concrete anchors stabilize the pipelines.

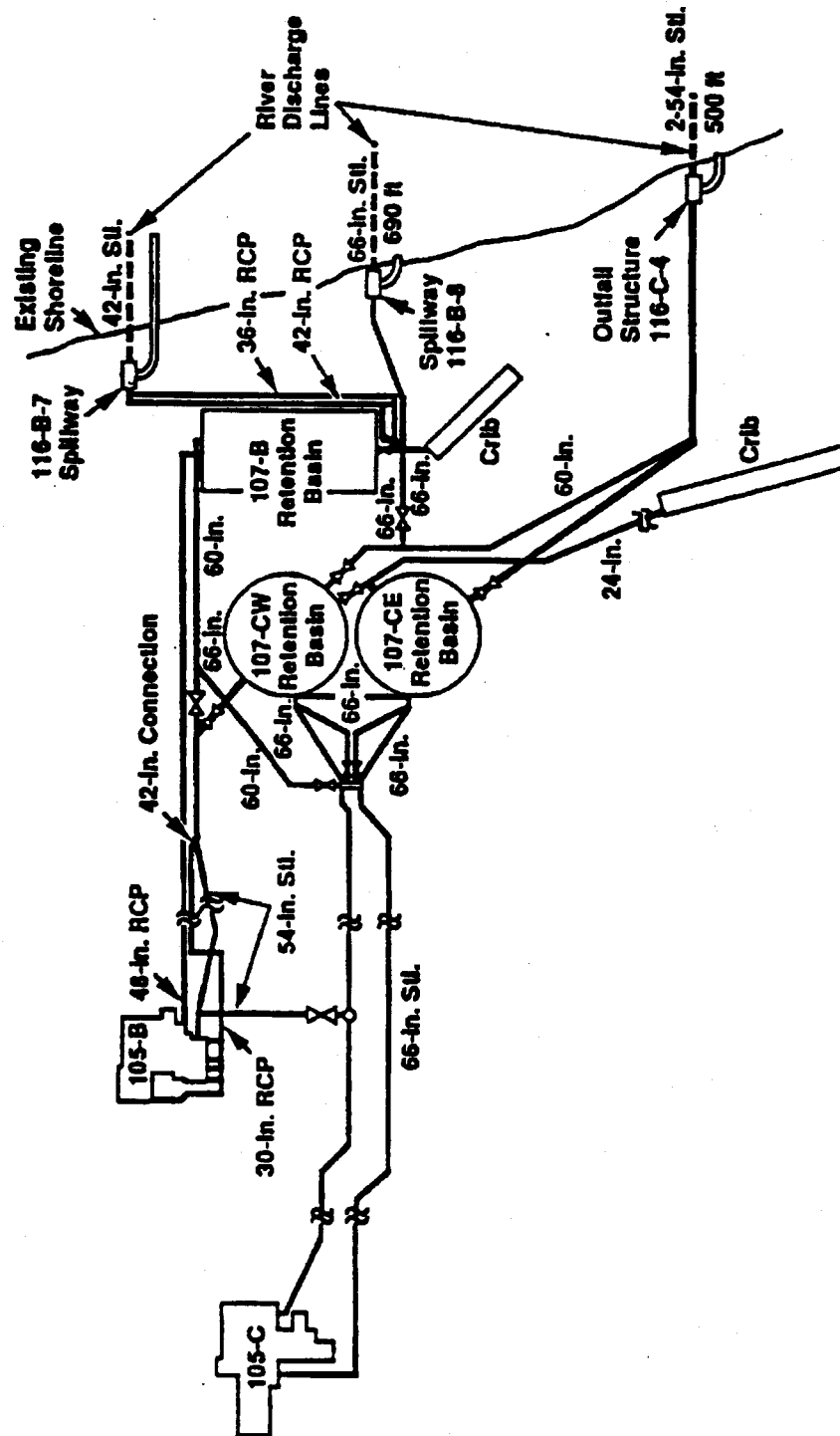
The two parallel pipelines originally extended 300 ft. The side-scan radar shows the river bed to be smooth. The two pipes and associated structures extend about 80 ft offshore and protrude 4 to 8 ft above the riverbed. No buried or exposed pipelines could be found further offshore with any of the geophysical instruments (WHC 1994). The two pipelines could not be clearly identified, possibly due to what appears to be large pieces of debris or rip rap resting on them. There are broken pipe sections marked with stakes, buried on the riverbank just upstream of the outfall structure, that were damaged and removed from the river in 1946.

2.1.5 H Pipelines

The H Reactor effluent system consists of the 116-H-5 Outfall structure and discharge piping, which consists of two 60-in.-diameter carbon steel lines with ½-in.-thick walls (Figures 10 and 11). In the early 1960s, the 100-H Area lines were re-anchored and buried after trapped air caused them to float out of place.

The river bed at this site consists of cobbles with occasional large boulders. The two 60-in.-diameter pipelines extend about 500 ft into the river. Both pipelines are buried along the entire alignment at a depth of 3 to 8 ft. There is no evidence on the side-scan sonar, ground penetrating radar (GPR), or bathymetric data that the pipeline outlet ends are exposed on the river bed (WHC 1994).

Figure 2. Reactor Retention Basin System, B and C Reactors.



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Figure 3. Profile 116-C-4 Outfall to River.

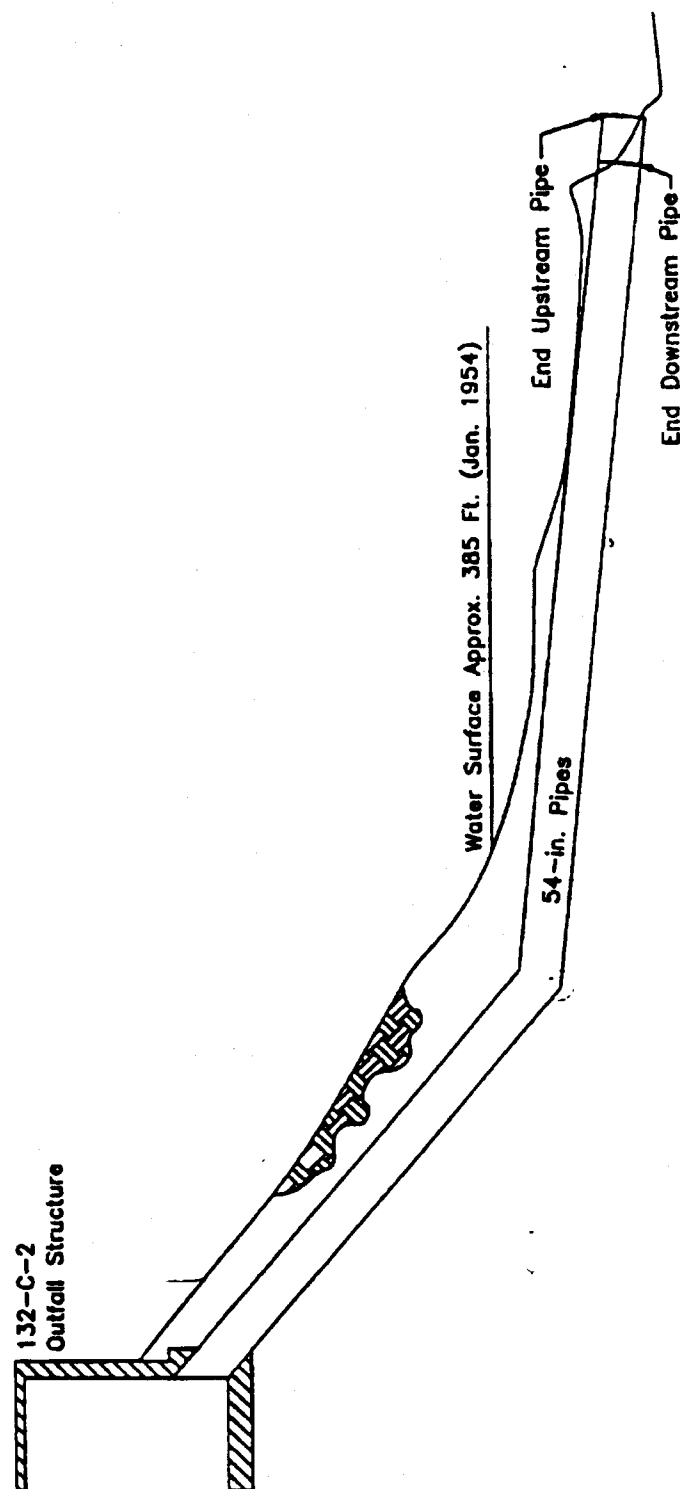


Figure 4. Profile and Top view of 100-D Pipeline.

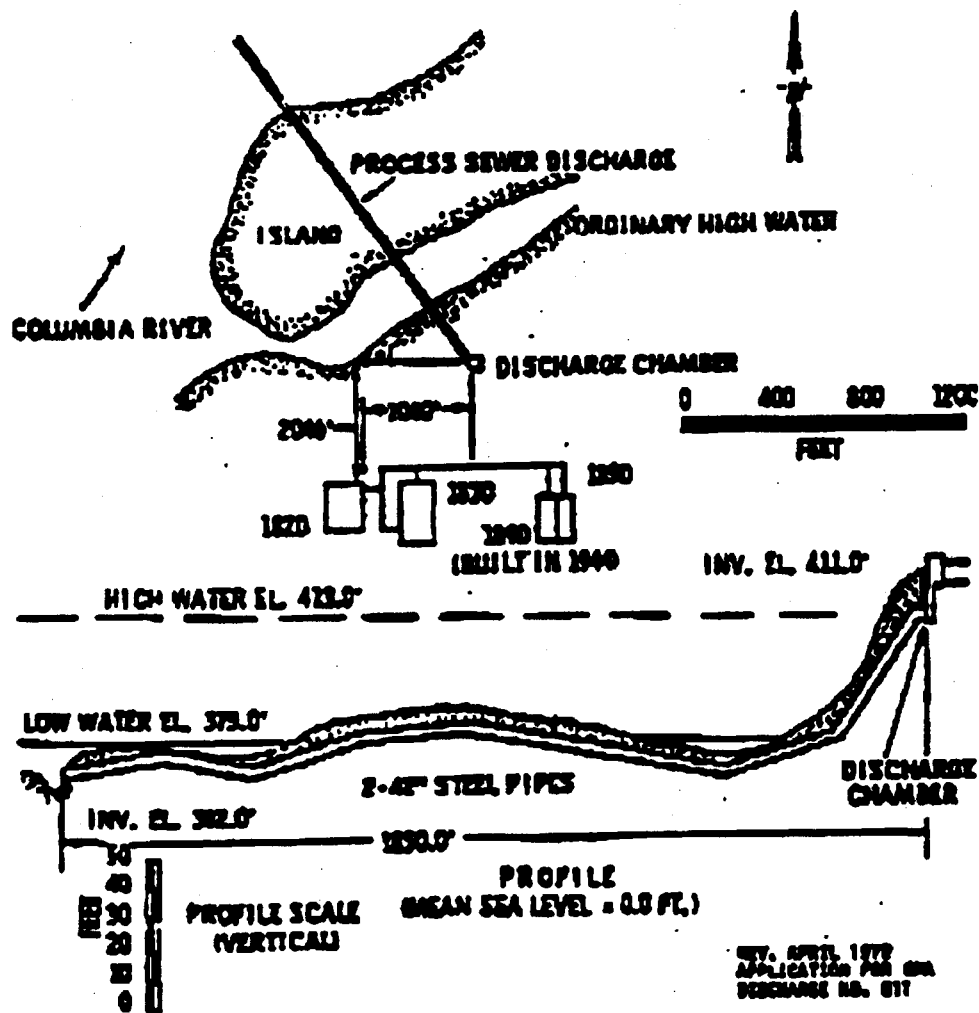


Figure 5. Effluent System, D and DR Rectors.

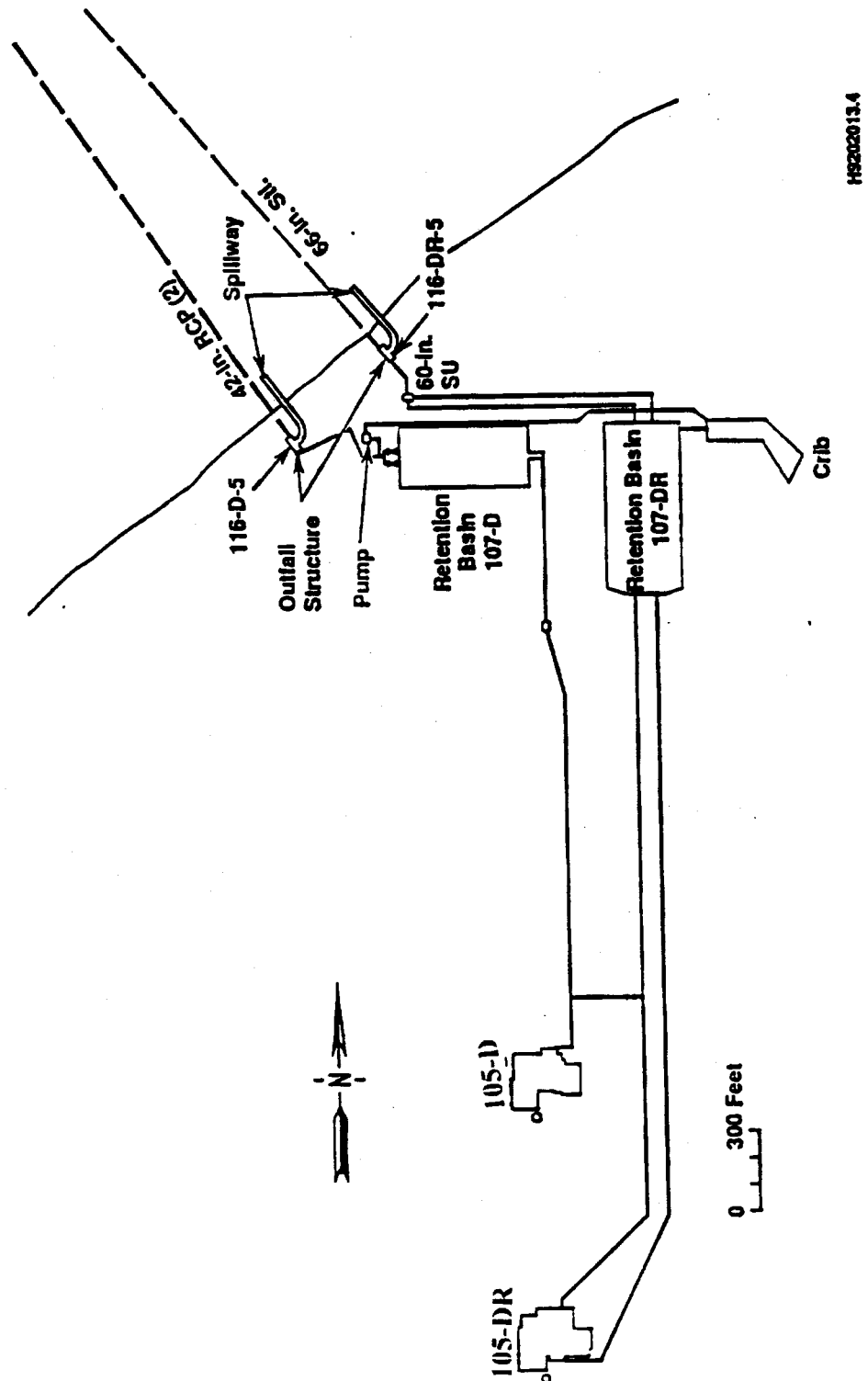


Figure 6. Profile 116-D-5 Outfall to River.

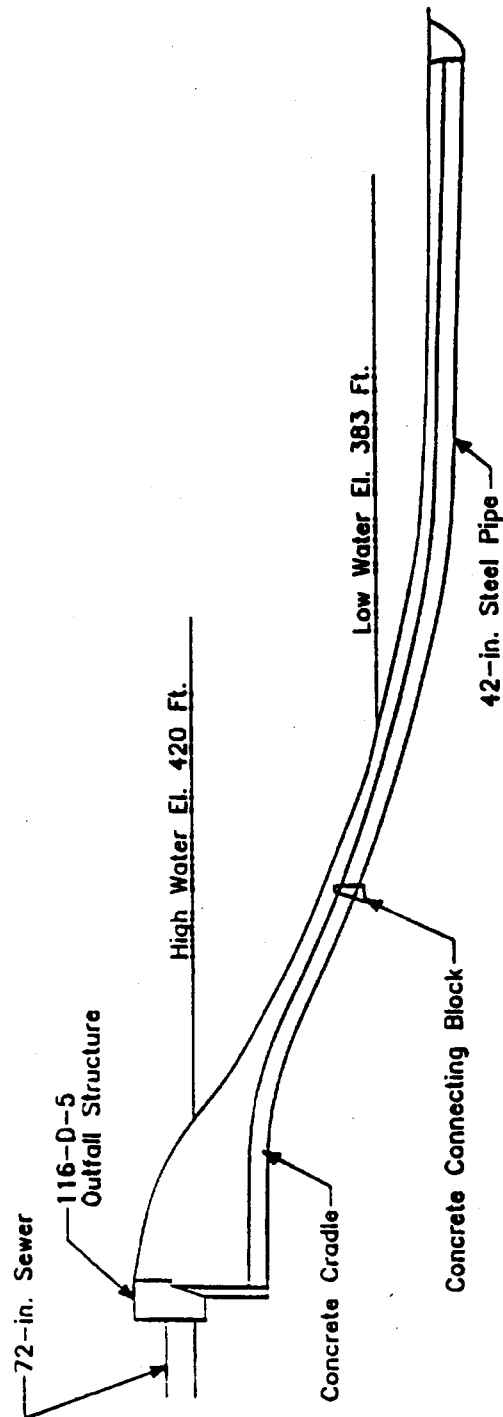


Figure 7. Profile 116-DR-5 Outfall to River.

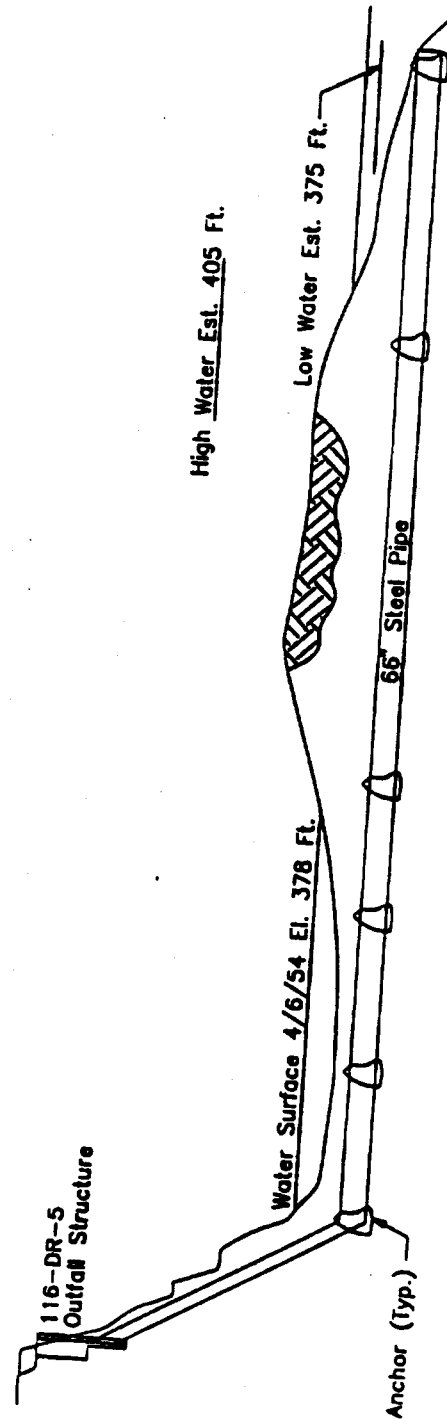


Figure 8. Effluent System, F Reactor.

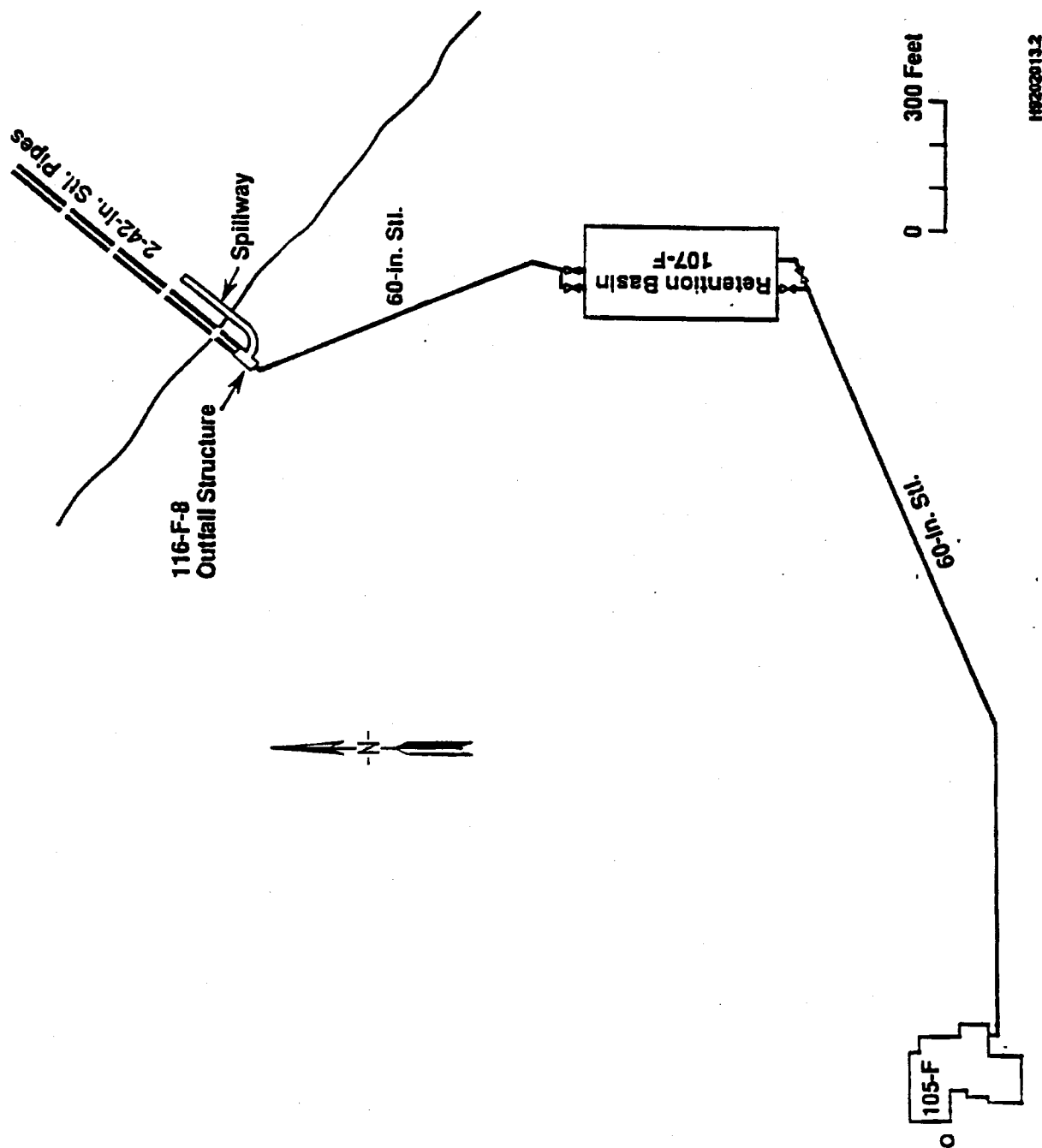


Figure 9. Profile 116-F-8 Outfall to River.

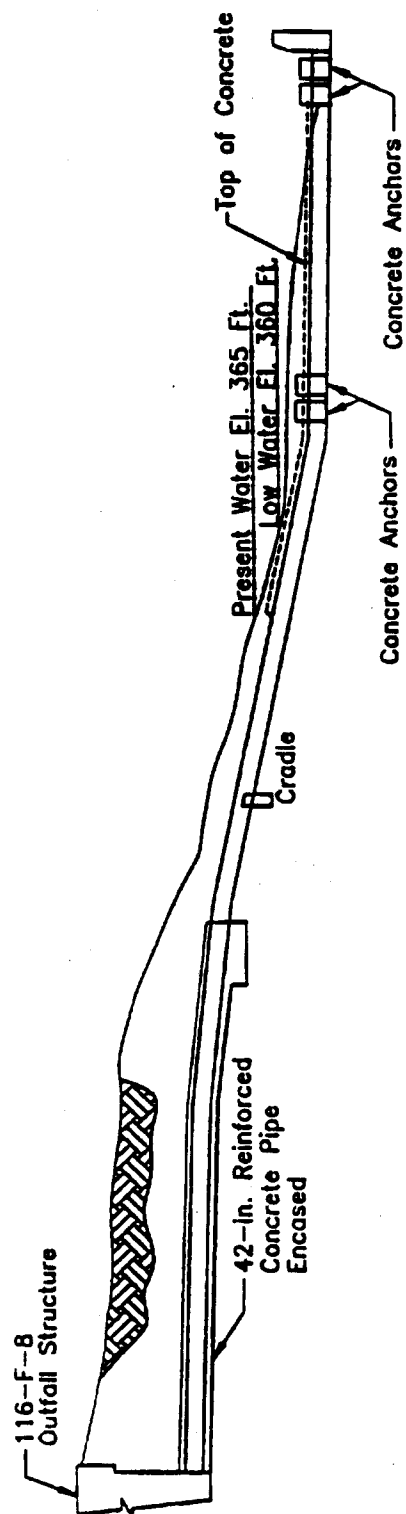
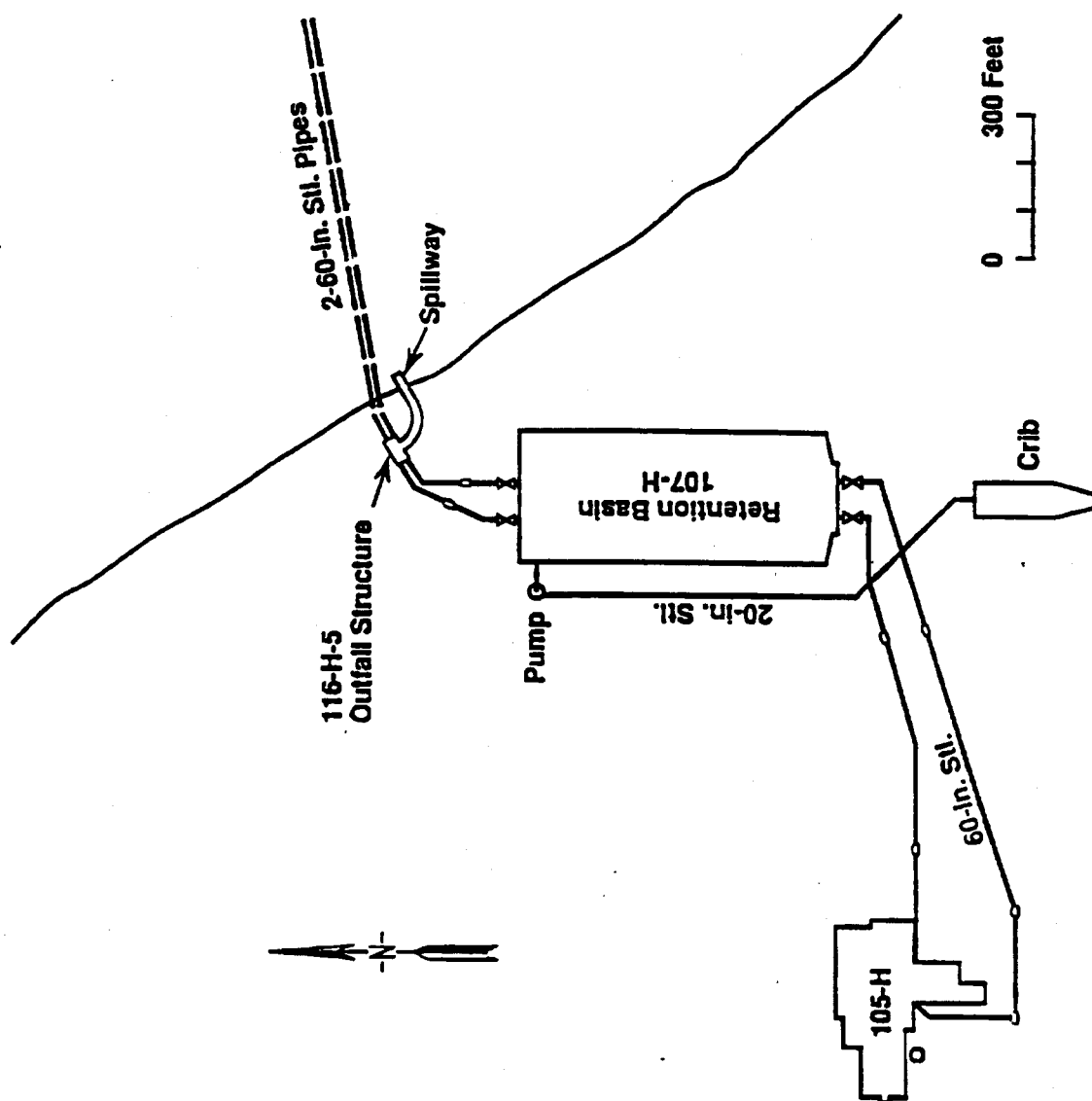


Figure 10. Effluent System, H Reactor.



2.1.6 K Pipelines

The K Reactor effluent system consists of the 116-K-3 Outfall structure and two welded 84-in.-diameter carbon steel discharge lines with ½-in.-thick walls (Figure 11).

This site's river bed consists of large cobbles, boulders, and possible other debris. The two pipelines extend about 250 ft into the river. The pipelines are exposed along most of the run. The pipelines protrude 1 to 3 ft above the riverbed at these exposures (WHC 1994).

2.1.7 N Pipeline

The 102-in. outfall line is a discharge point (Outfall Number 009) which disposed of raw river water used to cool the secondary cooling water for N Reactor. The discharge line extends approximately 400 ft into the Columbia River and turns upward where water is discharged through a 13-ft port (Figure 12).

The riverbed is covered with cobbles and patches of large boulders. The pipeline could not be imaged with the GPR, which worked successfully at all of the other sites. Two images on the bubble pulser data were interpreted to be the pipeline. They show the pipeline to be 8 to 10 ft below the surface, which is the GPR maximum capacity limit. The pipeline outlet is exposed on the river floor and has a relief of 3 to 4 ft (WHC 1994).

2.2 SURFACE WATER HYDROLOGY

Flow in the Columbia River is relatively swift at the effluent pipe outlets. The flow along the Hanford Reach is regulated by the Priest Rapids Dam, and river levels vary as much as 1.5 m (5 ft) daily. A complete description is presented by Neitzel (1996). Annual flow rates near Priest Rapids over the last 68 years have averaged nearly 3360 m³/s (120,000 ft³/s). Daily average flows range from 1008 to 7000 m³/s (36,000 to 250,000 ft³/s). Monthly means flows typically peak from April through June during spring runoff from winter snows, and are lowest from September through October.

Figure 11. Profile 116-H-5 Outfall to River.

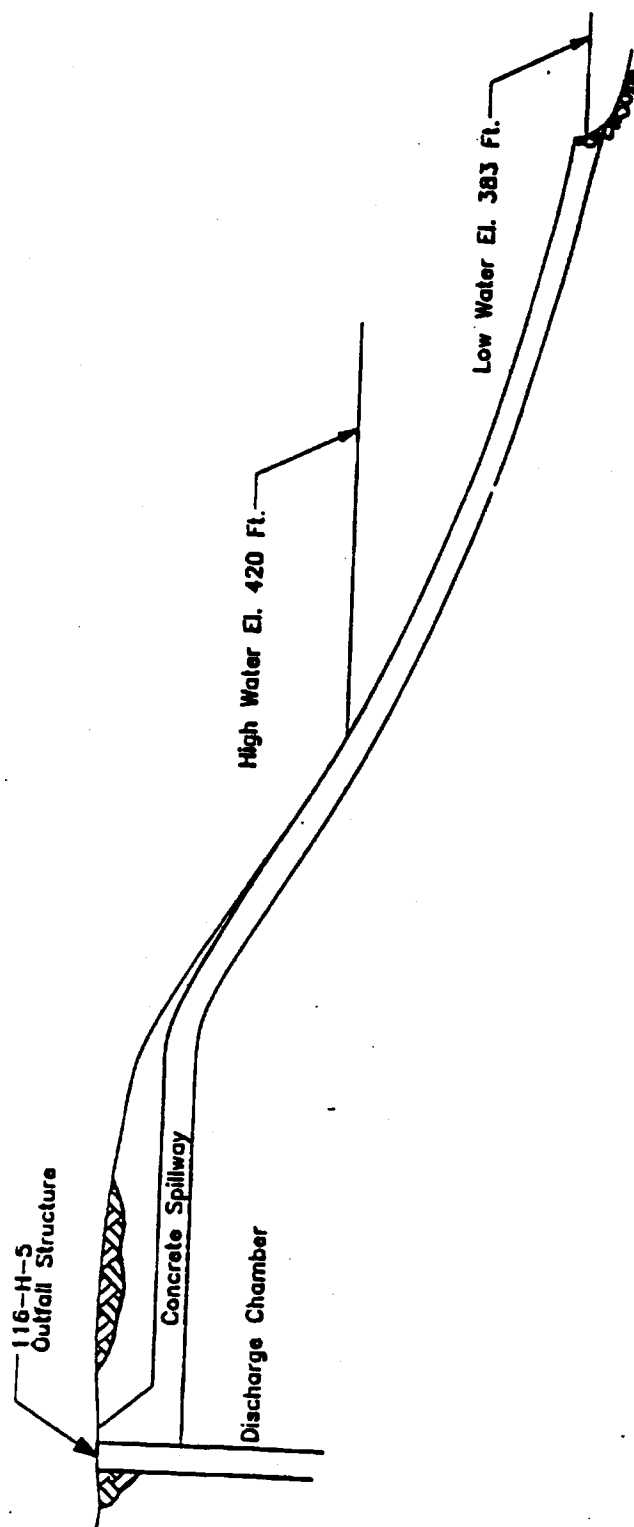
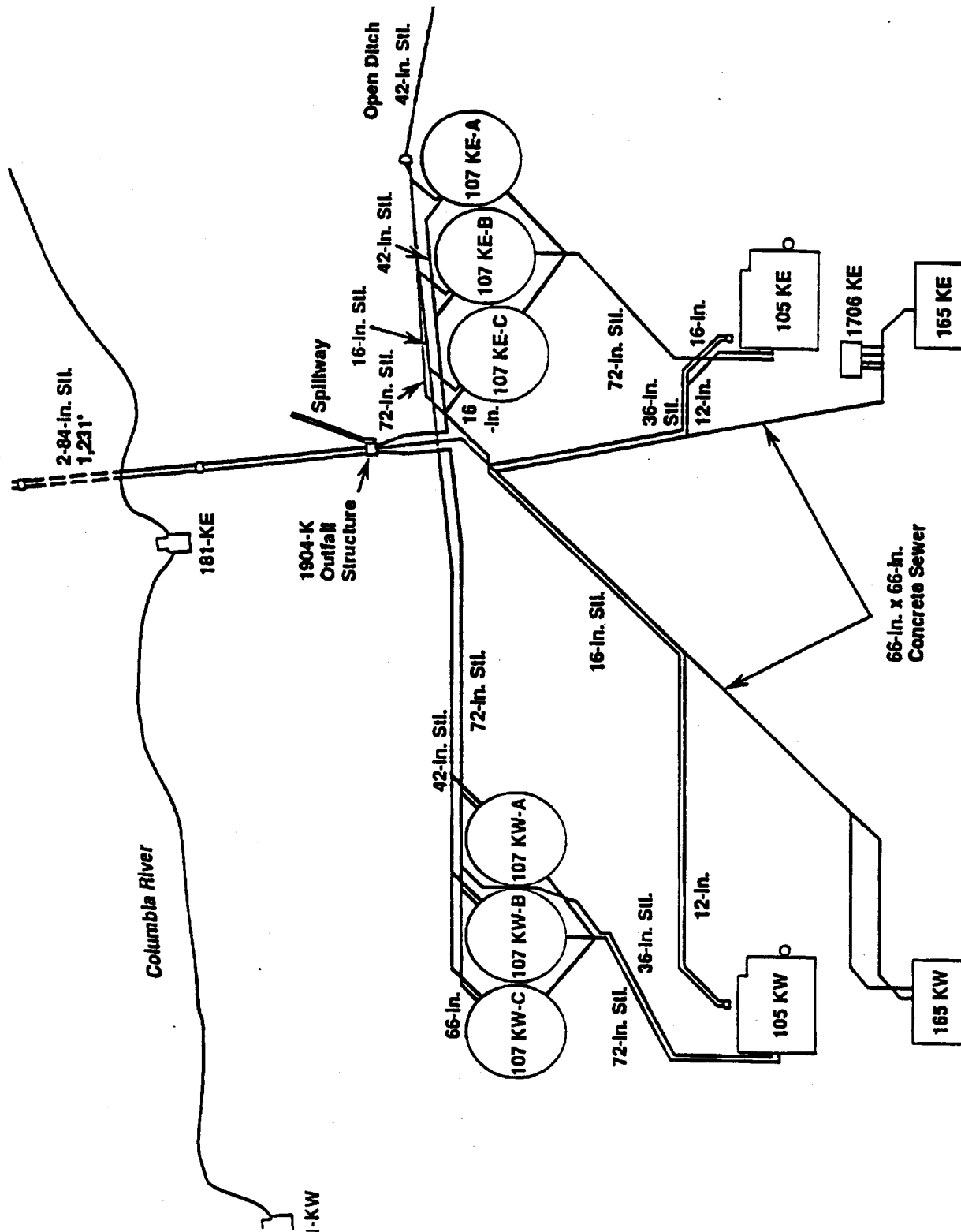
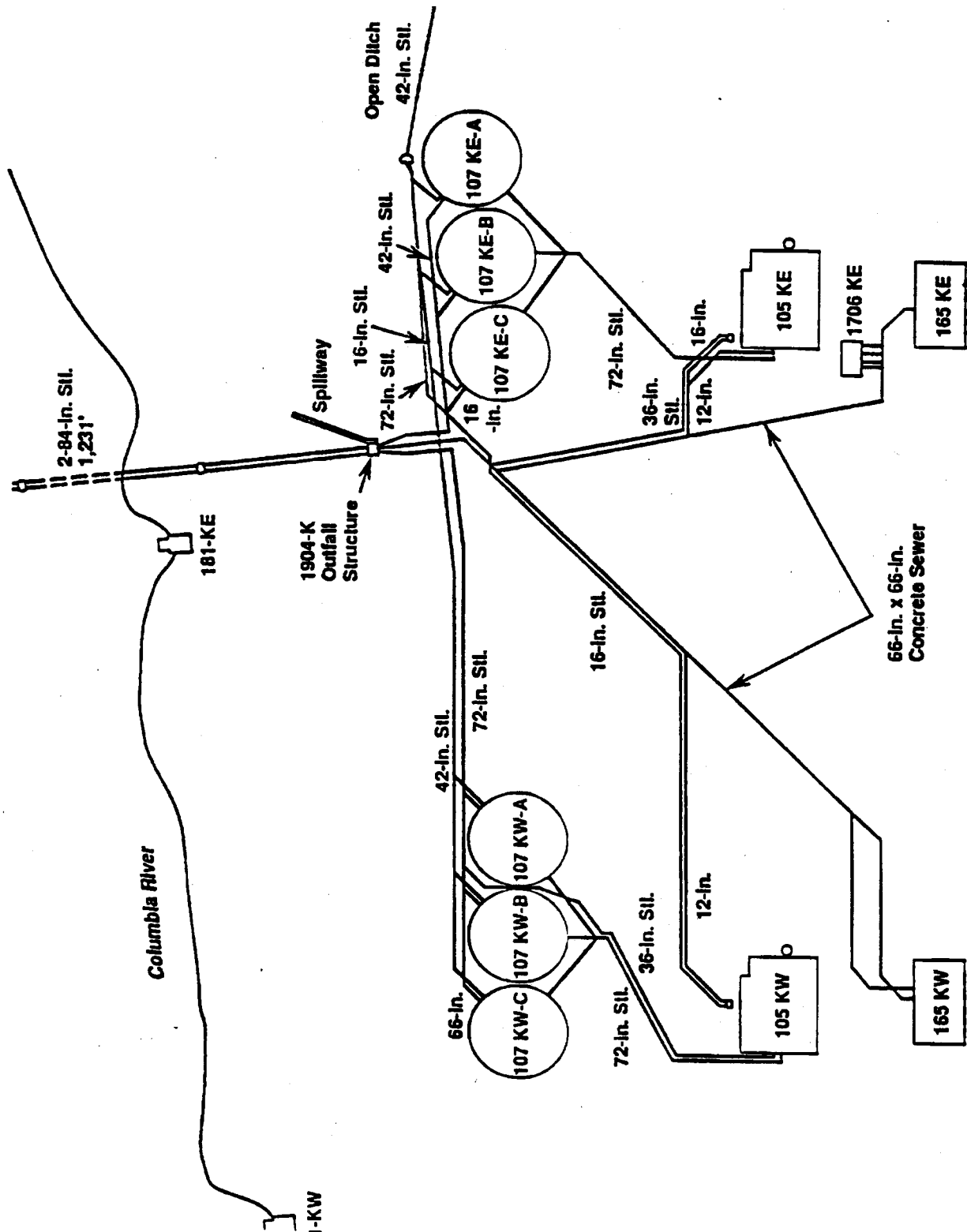


Figure 12. Reactor Retention Basin System, K Reactors.



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Figure 12. Reactor Retention Basin System, K Reactors.



H202013.3

2.3 SENSITIVE OR CRITICAL HABITAT

Sparse wetlands habitat exists in the Columbia River riparian zone. This zone supports stands of willows, grasses, aquatic macrophytes, and other plants. The wetland vegetation along the river is limited by seasonal and dam-controlled fluctuations in water level.

The Columbia River along the 100 Areas is of critical importance to salmon for spawning and juvenile habitat. Figure 13 shows the locations of salmon spawning grounds along the Hanford Reach in relation to the river effluent pipelines. Aquatic species of potential concern are the Columbia yellowcress (aquatic plant), shortfaced lanx (mollusk), Columbia pebblesnail (mollusk), and steelhead trout. Other species of concern likely to use the areas near the pipelines include bald eagles and American white pelicans.

2.4 PIPELINE CHARACTERIZATION STUDIES

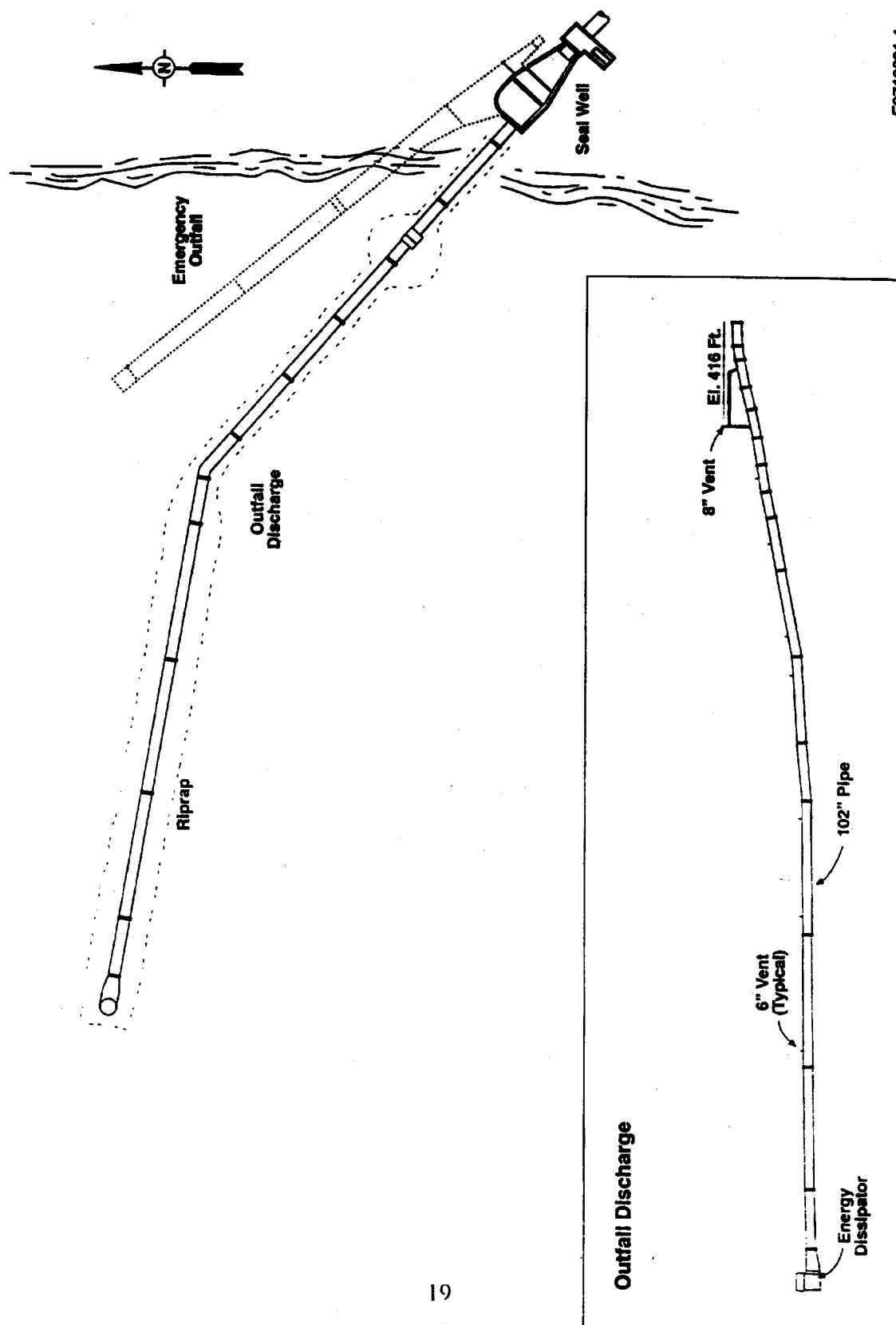
Several characterization activities have been carried out on the pipelines. They are briefly discussed below.

2.4.1 Beckstrom and Steffes (1986)

In the early spring of 1984, the deactivated effluent water lines for the 100-C, 100-DR, and 100-F reactors were radiologically and physically characterized. The pipelines were located; their sizes, number, and positions were verified, and their conditions were assessed. These investigations showed that pipe segments were missing from the 100-F pipelines. In about 1987, a missing pipe section was discovered buried on the riverbank upstream of the spillway. It is not clear if the contractor filled in the pipe segment holes and pipe with fill material, or covered the holes and contoured the immediate area. An internal pipe inspection would clarify the configuration.

Pipe section and sediment samples were collected and analyzed for radioactivity. The predominate isotopes in the lines are Europium-152 and 154. The highest concentration came from interior pipe scraping samples. For each sample tested, the isotopic concentrations in the sediment were less than in the scraping. Most of the activity seemed to be fixed within the rust on the interior pipe surface, from which the scrapings were collected. Table 3 lists the radiological data from the sampled 100-C, 100-DR, and 100-F pipelines. The contact dose rate on the outside of the pipe surface was zero. The contact dose rate on the interior surface was less than 1mrem/hr.

Figure 13. Top View and profile of N Reactor Effluent Pipeline Structures.



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Table 3. Data from UNI-3262 (Beckstrom and Steffes 1986).

1984 Data										
(pCi/g)										
Area	Location	Matrix	⁶⁰ Co	¹⁵² Eu	¹⁵⁴ Eu	¹⁵⁵ Eu	¹³⁷ Cs	Gross Alpha	Gross Beta	Total Activity
100-C	Offshore	Pipe section inner surface								
		Sediment	150	3400	580	51				
		Scale	600	7700	1300	150		12	937	949
100-DR	Offshore	Pipe section inner surface								
		Sediment	150	1700	310	16	25			
		Scale	670	7000	1200	83	28	6	799	805
100-F	Offshore	Pipe section inner surface								
		Sediment	120	6500	1000	73				
		Scale	330	12000	1900	93		27	2919	2946
1995 Values (Decayed 11 yrs)										
100-C	Offshore	Pipe section inner surface								
		Sediment	35.6	1865.5	360.2	0.8				
		Scale	142.4	4224.9	807.3	2.2		12	712	723
100-DR	Offshore	Pipe section inner surface								
		Sediment	35.6	932.8	192.5	0.2	19.4			
		Scale	159.0	3840.8	745.2	1.2	21.7	6	607	613
100-F	Offshore	Pipe section inner surface								
		Sediment	28	3566	621	1				
		Scale	78	6584	1180	1		27	2217	2243
Co - cobalt	Eu - europium	Cs - cesium	Am - americium	Sr - strontium						

2.4.2 WHC (1994)

In April 1994, a comprehensive marine geophysical survey located and mapped the 14 effluent pipelines using navigation and echo sounding, side-scanning sonar, sub-bottom profiling, seismic reflection profiling, and GPR. The results indicated that all the pipe trenches were not filled in completely. These river bed irregularities are apparently causing turbulent flow conditions over the pipe trench locations, which is possibly causing the pipes to become uncovered.

2.4.3 BHI (1996)

In the summer of 1995, the interiors of the effluent pipelines at the 100-B and 100-D reactor sites were radiologically, chemically, and physically characterized using a robotic transporter for the sampling and characterization equipment. The purpose of the activity was to provide an indication of the conditions in all river effluent pipelines to help determine a proposed course of action for the riverlines.

These two pipelines, based on reactor operations, were expected to represent a worst-case scenario with respect to radiological contamination and physical deterioration. The pipelines inspected were the single pipeline from the 116-B-7 Outfall and the upstream pipeline from the 116-D-5 Outfall. The inspections documented each pipeline's interior condition via video recording, radiation monitoring measurement, and ultrasonic testing, and the pipe's thickness was determined. Interior scale and sediment samples were collected. Fish swimming within the pipelines were recorded by the video camera.

Because an obstruction prevented the inspection of the last 40 ft of the upstream pipe at the 116-D-5 Outfall by video, an internal inspection of the parallel downstream pipe was also performed. It was originally planned that samples of interior scale and sediment would be taken at four locations within the length of each pipe. However, only three sediment samples were collected from the 100-B pipeline, as there was an insufficient volume for the fourth sample. Figures 14 and 15 show the locations of the samples for the 100-B and 100-D pipelines, respectively. The samples were analyzed for radiological constituents, gross alpha, gross beta, metals and total organic carbon.

Figure 14. Major Fall Chinook Salmon Spawning Areas in the Hanford Reach of the Columbia River.

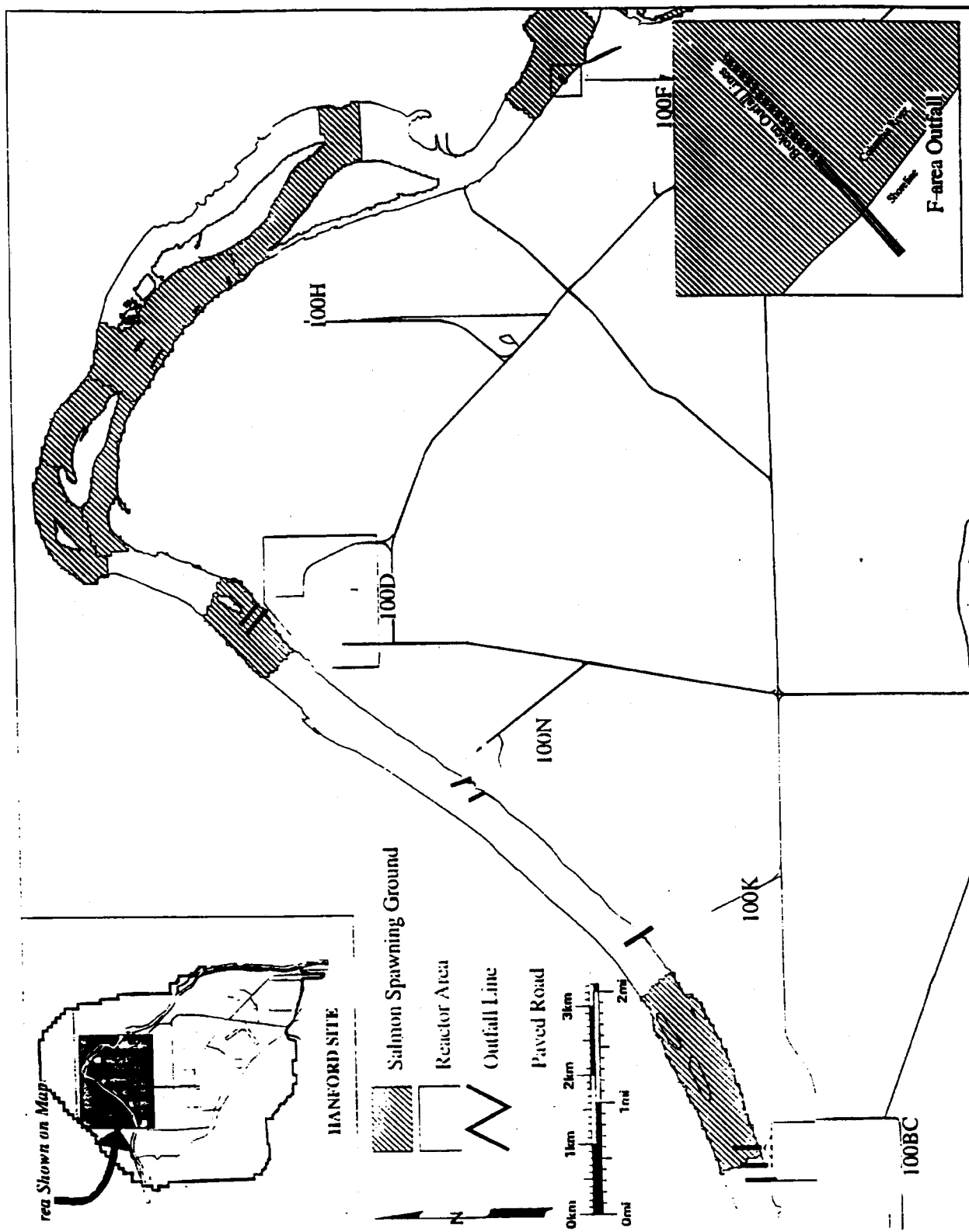


Figure 15. 100-B Pipeline Sampling Locations.

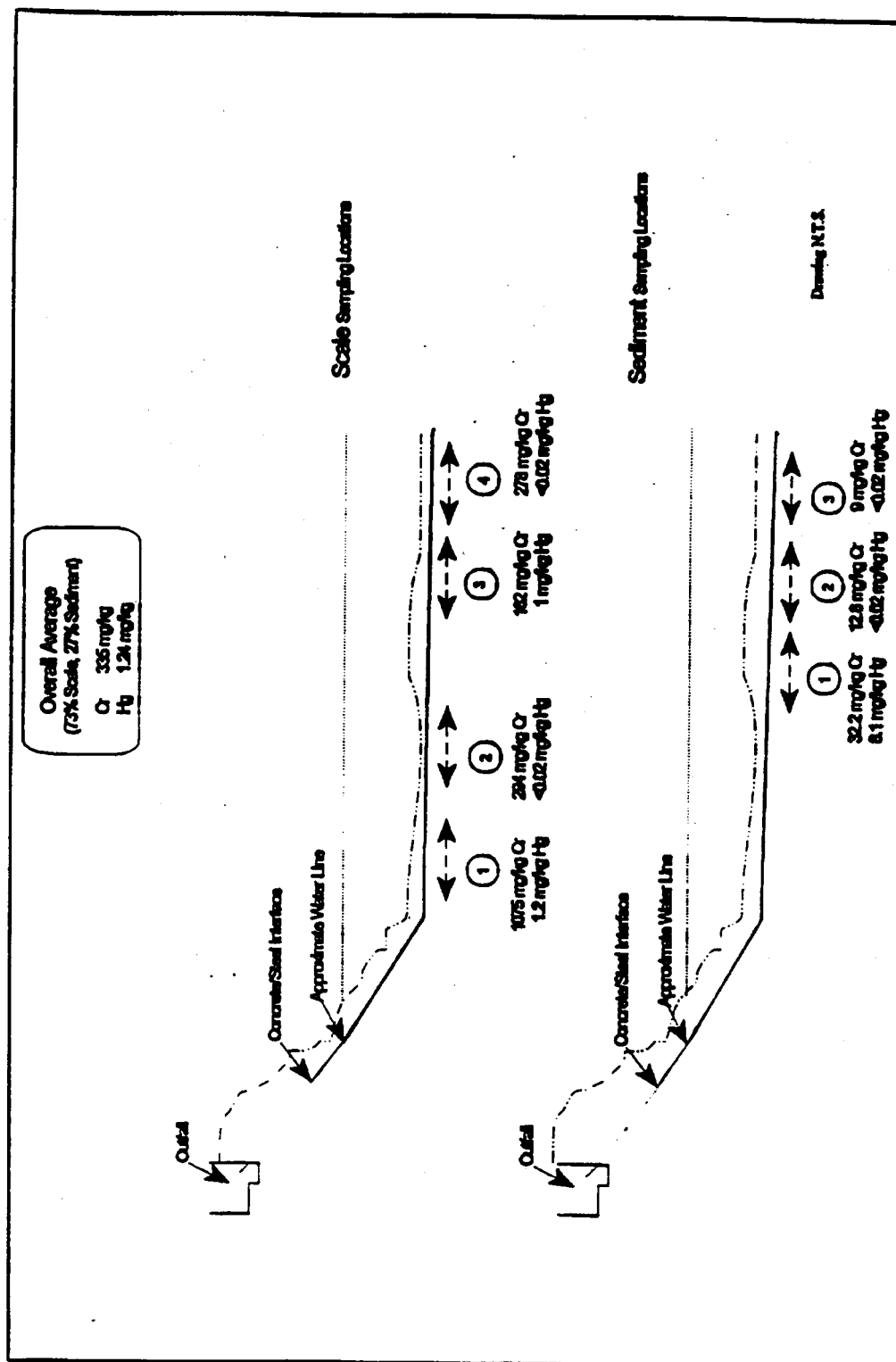
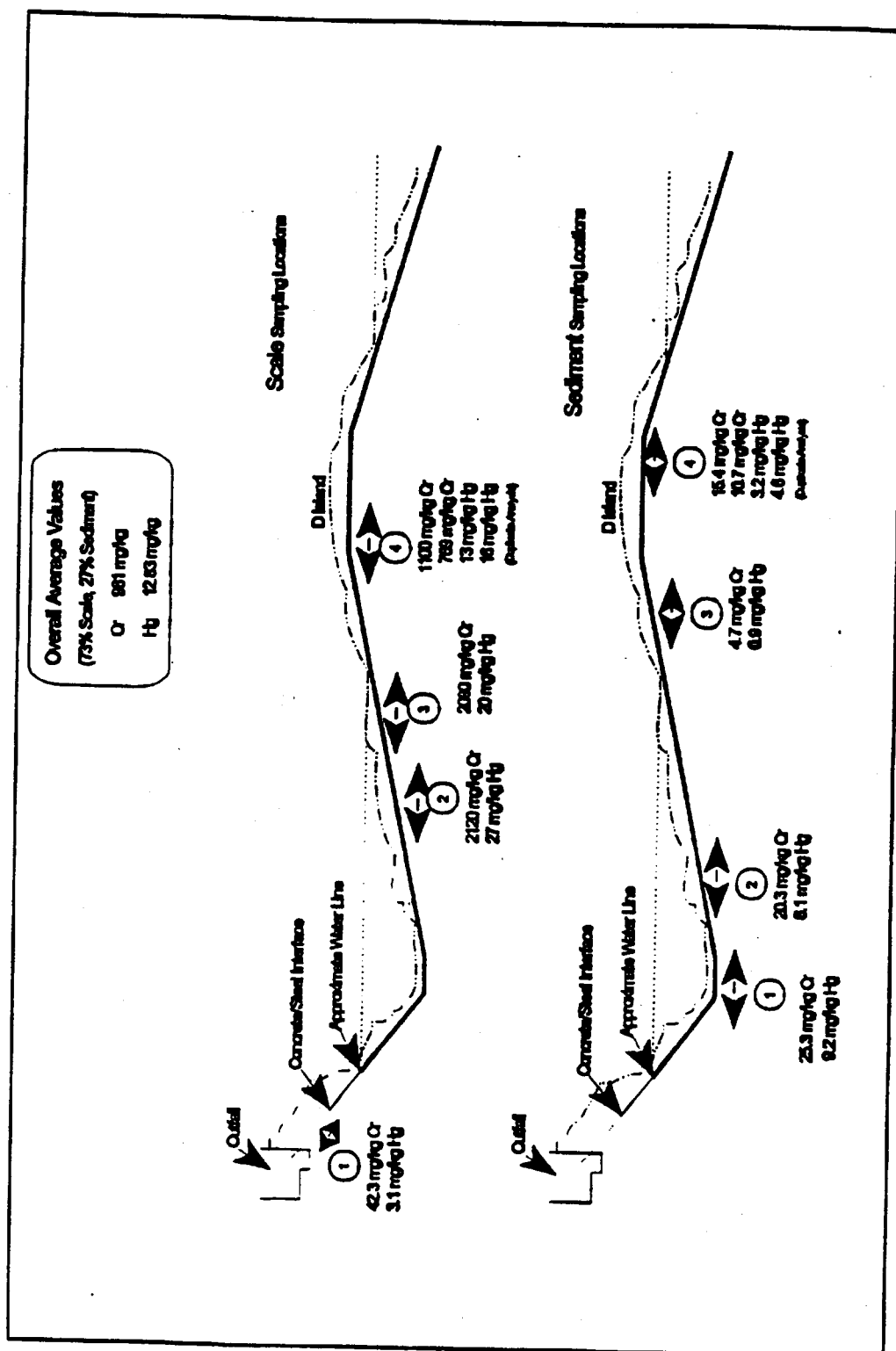


Figure 16. 100-D Pipeline Sampling Locations.



3.0 CONTAMINANTS OF POTENTIAL CONCERN

During the 1984 sampling of the C, DR, and F pipelines, analyses were only performed for radiological contaminants. The major radionuclides found were Co-60, Cs-137, Eu-152, Eu-154, and Eu-155. The concentrations of the radionuclides in loose scale and pipe scrapings for the 100-C, 100-DR, and 100-F pipelines are given in Table 3, with the 1984 concentrations decayed to 1995. The concentrations in the scale tend to be larger than those in the sediment. Tables 4 and 5 give the concentrations for radionuclides in scale and sediment for the 100-C and 100-D pipelines from the 1995 sampling; these concentrations are compared to the 1984 concentrations decayed to 1995 values from the 100-B and 100-DR pipelines, respectively. In most cases, the measured concentrations in 1995 are lower than the decayed values based on the 1984 samples.

In 1995, the scale and sludge samples from the 100-B and 100-D pipelines were analyzed for a suite of metals. Tables 6 and 7 give the concentrations, by sample location along the pipe, for the 100-B and 100-D pipelines, respectively. The constituents in the lower part of the tables are expected to be in carbon steel in some quantities, depending on the manufacturer and the time of manufacture. Since the pipelines were constructed during or soon after World War II, the carbon steel could have been obtained from a variety of sources. Most of the metals in the upper part of the tables (arsenic, cadmium, silver, selenium) have concentrations below the analytical detection limit. However, the concentrations of chromium and mercury were above detection limits, and in the case of chromium, over 1000 ppm in the scale for some of the samples.

The radiological and chemical contaminants of potential concern for this assessment are taken from the 1995 BHI robot sampling of the scale and sediments in the B and D pipelines.

4.0 RISK ASSESSMENT

The technical definition of risk involves a combination of exposure and toxicity. If an exposure pathway from the source to a receptor (human or ecological) does not exist, there is no risk. Also, if the constituent has no toxic effect on the receptor, there is no risk, even when an exposure pathway is possible. The radionuclide levels and metal concentrations inside the pipelines could pose a risk for some pathways. Thus, the following text reviews potential exposure pathways: external exposure from gamma-emitting radionuclides, and ingestion and inhalation of radionuclides and metals for humans or aquatic organisms (both under current conditions, and if sections of pipe should break loose in the future).

Table 4. 100-B/100-D Gamma Isotope Data.

Lab ID	Matrix	Area	Location	QC*	⁶⁰ Co	¹³² Eu	¹⁵⁴ Eu	¹⁵⁵ Eu	¹³⁷ Cs	⁴⁰ K
BOGCKJ3	Scale	B1	330-360		14	13	1.4	3.1	0.8	13
BOGCKJ5	Scale	B2	385-415		6.5	7.2	1.3	1.2	1	9.3
BOGCKJ7	Scale	B3	610-640		7.9	6.9	1.5	1.4	1.5	11
BOGCKJ9	Scale	B3	610-640	S	199	1760	181	11.1	0.95	
BOGCKO	Scale	B4	700-730		11	23	3.2	4	1.9	16
			UNC C Data ('95)		142	4225	807	2		
BOGCK2	Sediment	B2	615-645		9.7	15	9.8	6.2	2.9	110
BOGCK4	Sediment	B3	725-735		0.72	2.3	1.2	1	0.47	25
BOGCK6	Sediment	B3	725-735	S	0.338	0.47	0.42	0.17	0.11	
			UNC C Data ('95)		36	1866	360	1		
BOGCM7	Scale	D2	550-600		190	2200	220	8.5	3.6	13
BOGCM3	Scale	D3	600-650		190	2200	220	8.5	3.6	13
BOGCM4	Scale	D4	850-900		340	3200	330	25	5.4	150
BOGCL9	Scale	D4	850-900	D	190	1800	190	9.9	3.8	120
BOGCM9	Scale	D4	850-900	S	6.76	8.44	1.12	0.09	1.56	
			UNC DR Data ('95)		159	3841	745	1	22	
BOGCK9	Sediment	D1	320-375		7.2	100	11	2.4	5.7	14
BOGCL7	Sediment	D1	320-375	S	7.21	99.6	11.57	0.6	5.82	
BOGCL5	Sediment	D2	475-525		9.3	88	11	2.2	2.4	19
BOGCL1	Sediment	D3	755-800		8.2	41	5.8	4	1.7	50
BOGCL3	Sediment	D4	1040-1092		6.2	62	6.4	2.4	2.4	18
BOGCM1	Sediment	D4	1040-1092	D	6.3	68	8.2	2.5	1.5	20
			UNC DR Data ('95)		35.6	932.8	192.5	0.2	19.4	
BOGCK7	Silica Sand		Blank	B	0.56	1.5	1.1	2	0.46	10
BOGCM5	Silica Sand		Blank	B	0.54	1.9	1.2	1.8	0.4	10

*Note: Quality Control sample -- D = Duplicate, S = Split, B = Blank

Co = cobalt

Cs = cesium

Eu = europium

K = potassium

Table 5. 100-B/100-D Alpha/Beta Data.

Lab ID	Area	Location	Matrix	QC	pCi/g					Total U	Total Activity
					Alpha Energy Analysis	Gross Alpha	Gross Beta	²³⁵ Ni (pCi/L)	¹⁴ C	^{239/240} Pu	
BOGCK3	B1	330-380	Scale		4.98	6.79	44.8	125	64.6		51.6
BOGCK4	B1	330-360	Scale								<50
BOGCK5	B2	385-415	Scale		5.62	10.4	70.5	54.2	123		81
BOGCK6	B2	385-415	Scale								<50
BOGCK7	B3	610-640	Scale		11.4	17.1	36.4	181			53.5
BOGCK8	B3	610-640	Scale					79.9	0	42.9	<50
BOGCK9	B3	610-640	Scale	S	2.6	10.5	15.9			1.09	<50
BOGCK0	B4	700-730	Scale			13.5	30.2	41.2	96.4		31.6
BOGCK1	B4	700-730	Scale								<50
BOGCK2	B2	615-645	Sediment		8.3	19.9	277	118	-91.7		297
BOGCK3	B2	615-645	Sediment								<50
BOGCK4	B3	725-735	Sediment		9.4	12.7	306	129			319
BOGCK5	B3	725-735	Sediment					4.0	2.9	76.7	<50
BOGCK6	B3	725-735	Sediment	S		<6.2	19.6			<0.032	<50
BOGCK7	D2	550-600	Scale		9.5	55.5	8480	1020	78.4		6520
BOGCK8	D2	550-600	Scale								890.2
BOGCK9	D3	600-650	Scale		3.1	12.4	6150	904	144		6170
BOGCK0	D3	600-650	Scale								152
BOGCK1	D4	850-900	Scale		7.2	12.6	4250				4270
BOGCK2	D4	850-900	Scale	D	6	35.7	8060				8100
BOGCK3	D4	850-900	Scale					53.3			<50
BOGCK4	D4	850-900	Scale					548	86.1		<50
BOGCK5	D4	850-900	Scale	D				663	-5.4	150.7	<50
BOGCK6	D4	850-900	Scale	S		15.7	1308			2.01	<50
BOGCK7	D1	320-375	Sediment		9.4	10.1	207	90.4	-60.5		218
BOGCK8	D1	320-375	Sediment					42	-1.7	186.6	<50
BOGCK9	D2	475-525	Sediment	S	7.45	2.24	420			0.276	<50
BOGCK0	D2	475-525	Sediment					88.1	-60.5		422
BOGCK1	D3	755-800	Sediment		9.5	9.4	265	70.1	103		275
BOGCK2	D3	755-800	Sediment								<50
BOGCK3	D4	1040-1092	Sediment		7.3	26.2	2.73	26.6	-12.8		28.9
BOGCK4	D4	1040-1092	Sediment	D							<50
BOGCK5	D4	1040-1092	Sediment		9.9	20.8	2800	23.1	47.1		2820
BOGCK6	D4	1040-1092	Sediment	D							<50
BOGCK7	Blank	Blank	Silica Sand	B	8.6	0.9	101				101
BOGCK8	Blank	Blank	Silica Sand	B	4.64	0.11	0.3	0.164			0.404
BOGCK9	Blank	Blank	Silica Sand	B				-2.37			<50

QC = Quality Control
Ni = nickel
H = hydrogen
C = carbon
Pu = plutonium
U = Uranium

Table 6. 100-B Chemical Contaminant Summary.

	Lab #	BOGCG8	BOGCG9	BOGCH0	BOGCH9	BOGCH1	BOGCH4	BOGCH2	BOGCH3	BOGCK8
	Area	B1	B2	B3	B3	B4	B1	B2	B3	B3
	Location	330-380	385-415	610-640	610-640	700-730	600-610	615-645	725-735	725-735
	Matrix	Scale	Scale	Scale	Scale	Scale	Sediment	Sediment	Sediment	Sediment
	QC				S					S
mg/kg	<				<					
	TOC	2.71	1.73	3.02	21	1.93	8.52	7.56	1.33	2400
	<	<	<	<	<	<	<	<	<	<
	As	7.55	7.55	7.55	130	7.55	7.55	7.55	7.55	25
	<									
	Ba	56.3	43.6	45.8	130	50.7	109	46.9	30.6	56
	<	<	<	<	<	<	<	<	<	<
	Cd	1.75	1.75	1.75	17	1.75	1.75	1.75	1.75	1.3
	<									
	Cr	1075	294	162	4300	278	32.2	12.8	9	24
<	<	<	<	<	<	<	<	<	<	
Pb	5.75	5.75	5.75	76	5.75	44.6	10.3	11.8	14	
<										
Hg	1.2	0.02	1	1.2	0.2	8.1	0.02	0.02	0.12	
<	<	<	<	<	<	<	<	<	<	
Ag	3.35	3.35	3.35	5.4	3.35	3.35	3.35	3.35	3.35	1
<	<	<	<	<	<	<	<	<	<	
Se	4.25	4.25	4.25	120	4.25	4.25	4.25	4.25	4.25	22
	% Solids	33.8	35	33.9	27.56	28.8	39.4	69.1	24.3	22.35
mg/kg	<				7300					7900
	<				15000					14000
	<				39					29
	<				1400					280
	<				690000					28000
	<				160					100
	<				2300					4700
	<				260					580
	<				16					16
	<				5.4					52
	<				920					210

Note: "<" indicates a value less than the method detection limit.

QC - Quality

Control

TOC - total organic
carbon

As - arsenic

Ba - barium

Cd - cadmium

Cr - chromium

Pb - lead

Hg - mercury

Ag - silver

Se - selenium

Al - aluminum

Ca - calcium

Cu - copper

Mn - manganese

Fe - iron

K - potassium

Mg - magnesium

Na - sodium

Ni - nickel

V - vanadium

Zn - zinc

Table 7. 100-D Chemical Contaminant Summary.

Lab ID	BOGCJ1	BOGCJ2	BOGCN2	BOGCJ3	BOGCN3	BOGCN4	BOGCN5	BOGCN6	BOGCN7	BOGCN8	BOGCN9	BOGCN10	BOGCN11
Area	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12	D13
Location	80-125	560-890	600-950	850-900	850-900	850-900	850-900	850-900	850-900	850-900	850-900	850-900	850-900
Matrix	Scale	Scale	Scale	Scale	Scale	Scale	Scale	Scale	Scale	Scale	Scale	Scale	Scale
OC	Scale	Scale	Scale	Scale	Scale	Scale	Scale	Scale	Scale	Scale	Scale	Scale	Scale
TOC	1.93	2.11	1.7	1.79	2	22	3.31	19000	2.37	2.66	3.49	3.2	0.0405
As	<	<	<	<	<	180	7.55	52	<	<	<	<	<
Be	181	51.7	69.3	41.5	48.2	54	49.8	70	26.2	9.4	36.4	33.9	1.4
Cd	<	<	<	<	<	8.7	1.75	<	<	<	<	<	<
Cr	42.3	2120	2090	1100	769	1800	25.3	48	20.3	4.7	15.4	10.7	<
Pb	50.4	202	102	100	102	82	713	400	113	31.3	51.6	50.3	5.75
Hg	3.1	27	20	13	16	39.7*	9.2	20.5**	6.1	0.9	3.2	4.6	<
Ag	<	<	<	<	<	<	<	<	<	<	<	<	<
Se	4.25	4.25	4.25	4.25	4.25	130	4.25	29	4.25	4.25	4.25	4.25	4.25
% Solids	10.6	22.03	22.3	37	28.7	32.15	40.4	41.61	43.7	39.8	21.9	64	N/A
Al						6900		15000					
Ca						1100		2100					
Cu						25		95					
Mn						750		550					
Fe						600000		280000					
K						180		340					
Mg						250		1400					
Na						270		390					
Ni						14		23					
V						<		19					
Zn						750		280					

Note: "<" indicates a value less than the method detection limit
 TOC - total organic carbon
 Cu - copper
 Pb - lead
 Ag - silver
 Fe - iron
 Se - selenium
 Al - aluminum
 Hg - mercury
 V - vanadium
 As - arsenic
 K - potassium
 Zn - zinc
 Ba - barium
 Mg - magnesium
 OC - Quality control
 Ca - calcium
 Mn - manganese
 D - duplicate
 Cd - cadmium
 Na - sodium
 S - split
 Cr - chromium
 Ni - nickel
 B - blank
 * Preliminary data, 39.7 mg/kg +/- 14.4 mg/kg
 ** Preliminary data, 20.5 mg/kg +/- 26.6 mg/kg

Physically, the pipelines may be open at the far end, and also at the holes (about 3 ft by 3 ft) that were cut in the sides for the Beckstrom and Steffes (1984) study. These holes and other structures associated with the pipes (such as concrete anchors) provide habitat for aquatic life; however, the fish that are likely to benefit the most are squawfish, which are a significant predator of young salmon (Wydoski and Whitney 1979). Possibly, sturgeon might also enter the pipes to rest out of the current. Currently, humans may only access the pipelines at the outfall structures at the B and D lines, and possibly from the river, if scuba diving.

The pipelines do not appear to impact salmon spawning areas.

4.1 RADIONUCLIDES

The toxicology of the radionuclides within the pipes would be of little concern from ingestion or inhalation routes for either humans or fish, as evidently do not get flushed into the main body of the river and are in particulate form.

No dose is calculated for humans, because no current exposure pathway exists. Because Beckstrom and Steffes (1986) reported a contact dose rate for the interior surfaces of the pipes (once they are out of the water and dry) to be less than 1 mrem/hr, there is no reasonable pathway of concern to human health if the pipes remain stable. In addition, the concentrations of the radionuclides in 1995 were generally less than the concentrations predicted by the decay from the 1984 concentrations.

The only pathway of potential significance is for fish, such as sturgeon and squawfish, which may enter the pipes and rest for a time. If so, they could be exposed to contamination from the radionuclides present and to the metals in the sediment and scale. Ingestion of the sediment particulates by fish inside the pipes is possible. The radionuclides of highest concentrations are the europium series and Cobalt-60. Europium is relatively insoluble and lacks biological function; consequently, its absorption and food chain transfer are not expected (Driver 1994). Cobalt-60 also has a low food chain transfer coefficient for fish feeding on contaminated prey (Driver 1994). Any effects to fish from ingesting contaminated particulates are expected to be limited to the individual fish, not to a community or population. Therefore, the potential exposures would be small, occasional, and to the individual fish, rather than to the population. Squawfish, which are more likely than sturgeon to use the pipelines as a permanent habitat, could thus be exposed for longer periods. However, squawfish are considered an undesirable species because of their predatory behavior on young salmon.

If the pipelines were to break apart and release sludge and scale to the river, any effects would be a function of the amount of dispersion of the material. If the material were localized, a few fish could potentially be impacted by more concentrated radionuclides. If the material were widely dispersed over a larger area, the possibility for any effect would be small.

4.2 METALS

The concentrations of chromium and mercury in the pipe scale and sediment found in the BHI (1995) study, although high, suggest that they are not in a water-soluble form, so their toxicity to an occasional fish would be minimal. The insoluble form of the metals also presents no human or ecological risks. Concentrations in the pipeline water would establish whether the chromium and mercury were insoluble.

4.2.1 Chromium

Chromium exists in environmental systems in one of two oxidation states: trivalent (Cr^{+3}) or hexavalent (Cr^{+6}). Chromium, in the form of sodium dichromate, was used as a corrosion inhibitor in the water treatment systems during reactor operations. The species of chromium associated with sodium dichromate is Cr^{+6} ; however, after Cr^{+6} has existed in the environment, it is reduced to Cr^{+3} by weathering. On the one hand, Cr^{+6} is highly mobile in the environment and can be easily mobilized by water. On the other hand, Cr^{+3} is highly insoluble in water at the pH range of normal groundwater (pH 6-8), so is much less mobile in the environment (Olsen et al. 1994). The fact that the chromium was measured in the scale and sediment within the pipelines, suggests that it is in the form of Cr^{+3} , rather than Cr^{+6} . No chromium speciation analyses were run at the time, because the 24-hour laboratory holding time for a Cr^{+6} analysis could not be met in 1995.

There are significant differences in toxicity between hexavalent and trivalent chromium. Hexavalent chromium is a human carcinogen via the inhalation pathway, while trivalent chromium is an essential dietary element for humans and other mammals (Vitale et al. 1994). Also, hexavalent chromium is highly toxic to aquatic species; 11 ppb is the Washington State chronic fresh water quality criteria limit. For trivalent chromium, the maximum acceptable toxicant concentration to freshwater aquatic life, based on life cycle or partial life cycle exposures, varies according to the species. Rainbow trout is the most sensitive, with the range being 30-157 ppb (Eisler 1987).

4.2.2 Mercury

The use of mercury in the reactor processes at Hanford is not well documented. Historical information indicates that mercury vapor pumps were used in the 100-B Area. A more likely explanation of the presence of mercury in the pipelines is from broken manometers and thermometers. If the source of the mercury is the manometers and thermometers, then the mercury would most likely be in the form of elemental (inorganic) mercury.

Under certain environmental conditions, elemental mercury can be converted to methyl mercury, which is the most biologically toxic form, by bacterial and other natural processes. These conditions include acidic water, level of microbial activity, nutrient content, suspended sediment load, and redox conditions. However, these conditions are not expected to be the case for the Columbia River; the river water is not acidic, it has low organic content, and the microbial action tends not to be high.

Fish were observed in the pipelines in 1995 when a robot transporter equipped with a video camera was used to inspect and sample pipelines at 100-B and 100-D (BHI 1996). If aquatic biota are able to access the interior of the pipes, there is undoubtedly some exchange of pipe water with river water, diluting the concentration of Hg in water inside the pipes. As a point of information, Eisler (1987) reports that nationwide monitoring of whole fish from 1969 to 1981 demonstrated the highest Hg concentrations (0.33 to 1.7 ug/g FW [reported as mg/kg]) were in northern squawfish from the Columbia River Basin, attributed primarily to major cinnabar deposits and mining. Becker (1990) reported on the sampling of Hg in the Columbia River from 1971 through 1974, and found that Hg levels in sediments behind three Columbia River dams were as follows: 0.115 ug/g DW at Priest Rapids Dam; 0.331 ug/g DW at McNary Dam; and 0.096 ug/g DW at Bonneville Dam.

4.2.3 Water Concentrations of Chromium and Mercury from Analogous Site Information

In order to assess the toxicity of chromium and mercury to aquatic organisms in the river lines, some estimate of the soluble fraction of the metals is needed. Since no water samples were taken during the robotic inspection of the two pipelines, an indication of the solubility of the metals can be obtained from the concentrations of chromium and mercury in liquids and solids from reactor structures. Recently, samples of liquid and solids have been taken from several N Area structures as part of the decontamination and decommissioning of the reactor.

Samples of liquid and solids were taken from the following structures:

- 107-N-T-4 Tank
- 107-N Building Sump
- 107-N Pump Well
- 105-N Lift Station

The samples were analyzed for inductively coupled plasma metals, radionuclides, organics, anions, PCBs, and cyanide. The concentrations of chromium and mercury for these structures are summarized in Tables 8 and 9, respectively. For most of the structures, the concentrations of chromium and mercury in water were below the analytical detection limit. In addition, the toxicity characteristic leach procedure (TCLP) results for the solid material from those structures are also below the detection limit, which shows that the chromium and mercury are insoluble and, hence, not bioavailable.

At N Reactor, the two contaminants, chromium and mercury, were found in sediments and provide an example of solubility in a stagnant water condition. In the early years of operating, N Reactor (until 1973), sodium dichromate was used to inhibit corrosion in the primary cooling system the same as in the older reactors (DUN 1972). Therefore, the source of chromium in N Reactor sediments is probably the same as would be found in the effluent pipes from the older reactors. Since the pH of the water in the N Reactor facilities was similar to the pH of river water (near neutral), the comparisons of concentrations in sludge and water should provide an

illustrative example of the relationship that might be expected in the effluent pipes. Water and solids concentration data from the other reactors will become available within a relatively short time and may provide more information on the metals that went out through the riverlines. Actual water and sediment samples should be taken from the pipes before final remedial action designs are chosen.

Table 8. N Reactor Structures Metal Sampling Results – Chromium.

Structure	Water ug/L (ppb)	Solids ug/g (ppm)	TCLP ug/ml
1320-N Valve Pit	6 B ^a	268	0.062 U
107-N-T-4 Tank	2.7 U ^b		
107-N-T-4 Tank Dup	2.7 U		
107-N Bldg. Sump	13.4	231	0.058 U
107-N Pump Well	2.7 U	33.1	0.058 U
107-N Pump Well Dup		80.3	0.061 U
1314-N Tank	27.6		
105-N Lift Station	2.7 U	294	0.355 J ^c
105-N Lift Station Dup	2.7 U		

^a Metals analysis specific. Value is close to, but above detection limit. Additional error potentially associated with value.

^b Component not detected, value shown is detection limit. Detection limit for liquid is 3 ppb; detection limit for solid is 20 ppm.

^c Result shown is an estimate. Often results from a QC problem (e.g. low spike recovery) or a missed holding time. Additional error potentially associated with value.

Table 9. N Reactor Structures Metal Sampling Results - Mercury

Structure	Water ug/L (ppb)	Solids ug/g (ppm)	TCLP ug/ml
1320-N Valve Pit	0.19 B ^a	2.34 J	0.006 UJ
107-N-T-4 Tank	<0.1 U ^b		
107-N-T-4 Tank Dup	<0.1 U		
107-N Bldg. Sump	<0.1 U	1.96 J ^c	0.003 UJ
107-N Pump Well	<0.1 U	0.339 J	0.003 UJ
107-N Pump Well Dup		0.391 J	0.005 UJ
1314-N Tank	0.83		
105-N Lift Station	<0.1 U	43.05 J	0.005 UJ
105-N Lift Station Dup	<0.1 U		

^a Metals analysis specific. Value is close to, but above detection limit. Additional error potentially associated with value.

^b Component not detected, value shown is detection limit. Detection limit for liquid is 0.1 ppb; detection limit for solid is 0.1 ppm.

^c Result shown is an estimate. Often results from a QC problem (e.g. low spike recovery) or a missed holding time. Additional error potentially associated with value.

4.3 PHYSICAL RISKS ASSOCIATED WITH RIVER LINE BREAKUP

The major concern with leaving the river lines in place for the long term is that deterioration of the piping might lead to sections being extensively uncovered, becoming weakened by river currents, moving out of position, and eventually breaking off. The piping could then become a navigational hazard for boaters, and could potentially be swept downstream and cause property damage to bridges and pilings.

The wall thicknesses of the 100-B and 100-D pipelines were measured ultrasonically at three locations. Measured thicknesses varied from 0.385 to 0.480 in.; the original thickness was 0.50 in. Video observations indicated minimal deterioration of the three pipelines inspected. Anomalies observed included a possible settling of the bottom of the 100-B pipeline near its river outlet, indicated by broken chunks of scale along the pipe floor, and obstructions encountered in both the 100-D pipelines. In the upstream 100-D pipeline, the obstruction could not be identified because suspended sediment and the sampling arm hindered a frontal view. The obstruction in the downstream 100-D pipeline was recorded on the video and appeared to be a pile of river rock of varying sizes. No breaches in the pipe could be seen above the pile of rubble.

Preliminary analysis of pipe integrity showed that, at the current corrosion rate, it would take up to approximately 100 years for the pipes to completely deteriorate.

5.0 CONCLUSIONS

The concentrations of radionuclides and metals inside the pipelines provide no risk to humans at the present time. There is a potential risk from exposure to radionuclides and metals for the occasional fish that may swim into the pipeline. Although the concentrations of chromium and mercury in the scale and sludge within the pipeline are high, they are thought to be in the insoluble form based on data from analogous sources; therefore, they would pose minimal risk to the occasional fish. The concentrations of the radionuclides will continue to decrease over time due to radioactive decay. The pipeline structures themselves may present the greatest environmental risk by creating a preferred habit for undesirable fish that prey on young salmon.

Although the two pipelines inspected in 1995 appear to have suffered minimal deterioration, it is possible that they will become navigational hazards in the future. If the pipelines break apart and the scale and sludge are released to the river, the scale and sludge would be deposited on the riverbed at their current location, or would be moved downstream with the current. Any impact to humans or the environment would then be a function of the amount of dispersion of the material; however, due to the amount of material involved, the impacts would be expected to be minimal.

6.0 RECOMMENDATIONS

The conclusions stated that the risk to humans and the ecosystem from the radionuclides and metals in the pipelines are minimal, based on the possibility of exposure and the toxicity of the material. Consequently, the only risk from the pipelines, which appears to be minimal, is as a navigational hazard. The potential of this happening appears to be so small that additional actions, such as covering the exposed portions of the pipelines with rip rap, do not seem warranted.

The recommendation, therefore, would be to perform marine geophysical surveys similar to the Westinghouse Hanford Company (WHC) (1994) survey every five years or so to verify that the piping is intact. The WHC (1994) survey would be used as the baseline for these periodic surveys.

7.0 REFERENCES

- Becker, C. D., 1990, *Aquatic Bioenvironmental Studies: The Hanford Experience 1944-1984*, Elsevier, New York.
- Beckstrom, J. F. and J. M. Steffes, 1986, *River Discharge Lines Characterization Report*, UNI-3262, UNC Nuclear Industries, Inc., Richland, Washington.

- BHI, 1996, *100 Area River Effluent Pipelines Characterization Report*, BHI-00538, Bechtel Hanford Inc., Richland, Washington.
- Dauble, D. D. and D. C. Watson, 1990, *Spawning and Abundance of Fall Chinook Salmon (*Oncorhynchus tshawtscha*) in the Hanford Reach of the Columbia River, 1948-1988*, PNL-7289, Pacific Northwest Laboratory, Richland, Washington.
- DOE, 1994, *100 Area River Effluent Pipelines Expedited Response Action Proposal*, DOE-RL-94-79, Draft A. U. S. Department of Energy, Richland Operations Office, Richland Washington.
- Driver, C. J., 1994, *Ecotoxicity Literature Review of Selected Hanford Site Contaminants*, PNL-9394, Pacific Northwest National Laboratory, Richland, Washington.
- DUN, 1972, Douglas United Nuclear, Inc. Reactor and Fuel Production Facilities 1972 Environmental Release Report (DUN-8133). Douglas United Nuclear Inc., Richland, Washington.
- Eisler, R., 1986, *Chromium Hazards to Fish, Wildlife, and Invertebrates: A Synoptic Review*, Contaminant Hazard Reviews Report No. 6, Biological Report 85(1.6), Patuxent Wildlife Research Center, U.S. Fish and Wildlife Service, Laurel, Maryland.
- Eisler, R., 1987, *Mercury Hazards to Fish, Wildlife, and Invertebrates: A Synoptic Review*, Contaminant Hazard Reviews Report No. 10, U.S. Fish and Wildlife Service, Laurel, Maryland.
- Neitzel, D. A. (Ed.), 1996, *Hanford Site National Environmental Policy Act (NEPA) Characterization*, PNL-6415, Rev. 8, Pacific Northwest Laboratory, Richland, Washington.
- Olsen, K. B., J. Wang, R. Setladi, and J. Lu, 1994, *Field Screening of Chromium, Cadmium, Zinc, Copper, and Lead in Sediments by Stripping Analysis*, Environ. Sci. Technol., 28(12): 2074-2079.
- Vitale, R. J., G. R. Mussoline, J. C. Petura, and B. R. James, 1994, *Hexavalent Chromium Extraction from Soils: Evaluation of an Alkaline Digestion Method*, J. Environmental Qual. 23:1249-1256.
- WHC, 1993, *100 Area CERCLA Ecological Investigations*, WHC-EP-0620, Westinghouse Hanford Company, Richland, Washington.
- WHC, 1994, *Columbia River Effluent Pipeline Survey*, WHC-SD-EN-TI-278, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

BHI-01141
Rev. 0

Wydoski, R. S. and R. R. Whitney, 1979, *Inland Fishes of Washington*, University of Washington Press, Seattle, Washington.

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